

THE SPATIAL DISTRIBUTION OF LUNAR POLAR HYDROGEN DEPOSITS. V. R. Eke¹, L. F. A. Teodoro² and R. C. Elphic³, ¹Institute for Computational Cosmology, Department of Physics, Durham University, Science Laboratories, South Road, Durham DH1 3LE, UK (v.r.eke@durham.ac.uk), ²Astronomy and Astrophysics Group, Department of Physics and Astronomy, Kelvin Building, University of Glasgow, Glasgow G12 8QQ, UK, and ³NASA Ames Research Center, MS 245-3, Moffett Field, CA, USA

Introduction: The existence of hydrogen near the lunar poles was demonstrated by Feldman et al. [1; 2; 3] using data from the neutron spectrometer carried by the Lunar Prospector. Whether or not this hydrogen is concentrated into the permanently shaded ‘cold traps’ near to the lunar poles has not yet been convincingly determined. This is important because if the hydrogen is concentrated into the cold traps near to the poles, then it is probably locked up in a volatile compound. As the most likely candidate is water ice [4], this is of interest both for improving the understanding of the Solar System and for future lunar exploration. If the hydrogen is more diffusely distributed around the polar regions, then it is more plausible that it is merely the result of the solar wind implanting hydrogen into the regolith [5]. The excess polar hydrogen would result from the lower polar temperatures reducing the rate at which it diffuses away relative to more equatorial regions. Discriminating between these two scenarios requires an improved determination of the spatial distribution of the polar hydrogen. This paper describes the results of applying a newly developed pixion image reconstruction algorithm to the Lunar Prospector epithermal neutron data.

Pixon image reconstruction methods: In the presence of both an instrumental blurring, B , and some experimental noise, N , the measured data, D , can be related to the input image, I , via

$$D = I * B + N, \quad (1)$$

where $*$ represents the convolution operator. The task of an image reconstruction algorithm is to choose a reconstruction, I' , that both avoids unnecessary complexity and produces a residual field,

$$R = D - I' * B, \quad (2)$$

that is statistically equivalent to the anticipated experimental noise. The pixion reconstruction algorithm [6; 7] does this by imposing a spatially varying smoothing on the reconstruction, with the scale of this smoothing set by the local information content in the data. Thus, each pixion, which can be thought of as a set of spatially correlated pixels, contains the same information content. The reconstruction therefore looks smooth in this pixion basis and the image entropy is maximised.

Elphic et al. [8] introduced a variant of the pixion algorithm whereby the reconstruction pixel values are decoupled for two different types of pixel. In this way, it is possible to treat cold trap, or shadow, pixels as distinct from sunlit pixels. They constructed a shadow map for the south pole using the best available digital elevation maps and produced a decoupled reconstruction of the Lunar Prospector epithermal neutron data. While this showed that the data were consistent with significant concentrations of hydrogen into the cold traps, it did not address whether or not the data themselves actually justified decoupling the shadow pixels.

Figure 1 shows both coupled and decoupled reconstructions of the north and south pole Lunar Prospector epithermal neutron data. From this it is evident that decoupling the shadow pixels leads to significantly lower count rates emanating from the cold traps, which means higher hydrogen concentrations.

Analysis: In order to choose if the imposition of the shadow map prior to decouple cold trap pixels is necessary or not, one should consider the radial dependence of the mean reduced residual ($r = R/\sigma$, where σ comes from Poisson statistics) around the cold traps. For instance, if I really has deep, narrow dips in cold trap pixels, then a coupled reconstruction will place too many counts in the cold trap and try to compensate by placing fewer in the surrounding pixels. Referring back to equation (2), this implies that the mean residual would be negative at small radii, then cross over to positive values further away from the cold traps. By doing coupled reconstructions of many mock data sets, created using as input images the decoupled reconstructions in the right-hand column of Figure 1, it is possible to determine the radial bias in the residuals resulting from not decoupling the cold trap pixels. This variation can be fitted by the following function:

$$F(d) = \begin{cases} 0.032 \tanh\left(\frac{d-17}{10}\right) - 0.02 & d \leq 60 \text{ km;} \\ 0 & d > 60 \text{ km,} \end{cases} \quad (3)$$

where d is the distance, in km, from the centre of the cold trap. Having quantified the signature in the residual field that coupling the cold trap and sunlit pixels is producing, it is now possible to filter the reduced residuals looking for areas in the image where this error is being made. To

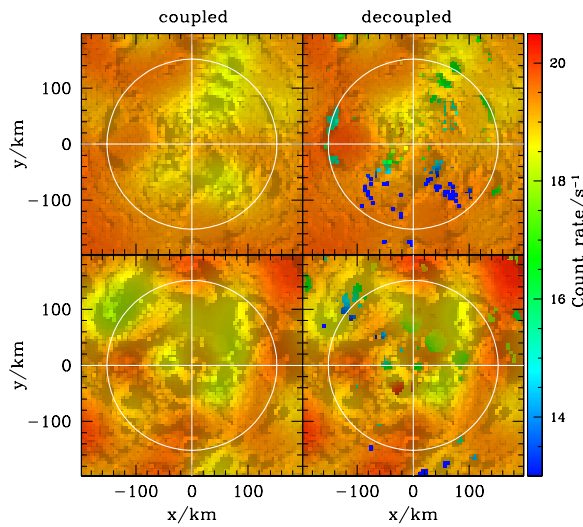


Figure 1: Reconstructed epithermal neutron count rate maps for the north pole (top row) and south pole (bottom row) Lunar Prospector data. The left-hand column shows the coupled reconstructions, where all pixel values are correlated, whereas the right-hand column includes the shadow map prior that allows the reconstruction to decouple the permanently shaded pixels from those that occasionally see sunlight. A count rate of ~ 13 per second corresponds to ~ 1 wt% water-equivalent hydrogen. The white circles represent latitudes $\pm 85^\circ$, and the shading represents the topography as imaged by Clementine.

this end, a shadowiness parameter, S , is defined as

$$S = r * F. \quad (4)$$

Positive S corresponds to a pattern in the residuals like that caused by the reconstruction smoothing over deep, narrow dips in count rate. Figure 2 shows the distributions of S coming from coupled reconstructions of the north and south pole data. The distributions are split by whether or not the pixels fall into areas of permanent shadow according to the independently determined shadow maps. It is evident from the figure, and confirmed by KS tests, that the shadow pixels have shadowiness values that are typically biased high relative to what would be produced by a true random field of residuals, which looks very much like the distribution of the sunlit pixels in Figure 2. Furthermore, the shadowiness is less biased for the south pole case where, as a result of the winter lighting conditions, the cold trap pixels are less

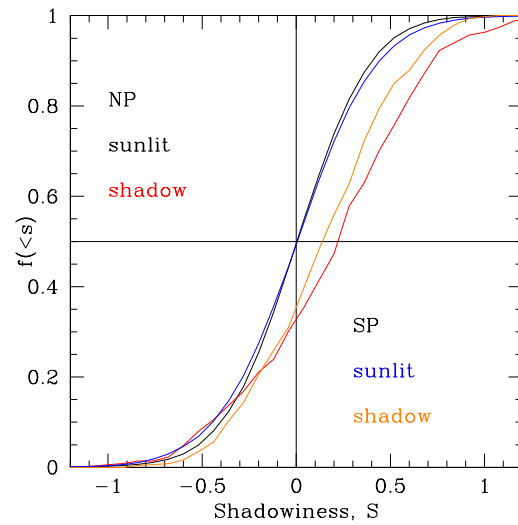


Figure 2: Cumulative distributions of the pixel shadowiness for both sunlit and shadow pixels for coupled reconstructions of both poles.

convincingly known from digital elevation maps. The Lunar Prospector epithermal neutron data alone pick out the cold trap pixels as special, and imply that the hydrogen is concentrated into cold traps.

Conclusions: By applying a specially developed pixon image reconstruction algorithm to the Lunar Prospector epithermal neutron data set, it has been shown that the excess hydrogen near to the lunar poles does need to be concentrated into cold traps. This implies that it is most likely to be in the form of water ice rather than solar wind implanted hydrogen. The results correspond to ~ 1 wt% water-equivalent hydrogen averaged within the more hydrogen-rich permanently shaded craters.

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